BEFORE THE STATE OF CALIFORNIA

PUBLIC UTILITIES COMMISSION

In Re: Pacific Gas & Electric, San Diego Gas & Electric, and Southern California Edison Applications for Approval of their 2018 Energy Storage Procurement and Investment Plans	)))))	**Applications 18-02-016, 03-001 & 03-002**

DIRECT TESTIMONY OF PAUL CHERNICK

CONCERNING ENERGY STORAGE TECHNOLOGY DIVERSITY

ON BEHALF OF SMALL BUSINESS UTILITY ADVOCATES

Resource Insight, Inc.

AUGUST 28, 2018

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I. Introduction

Small Business Utility Advocates (SBUA) submits these comments in accordance with the August 8, 2018 "Assigned Commissioner's and Assigned Administrative Law Judge's Ruling Requesting Comments on Issues Pertaining to Energy Storage Technology Diversity." The e-mail ruling of ALJ Stevens, dated August 14, 2018, granted an extension of time to Tuesday, August 28, 2018 to serve and file comments and Wednesday, September 5, 2018 to serve and file reply comments. These comments answer the five questions asked by the Assigned Commissioner and more generally frame SBUA's position on energy storage and diversity technology. These comments expand on comments SBUA filed on the utility procurement plans associated with the AB 2868 portion of these dockets.[1]

The storage sector is developing rapidly, with new technologies and implementation approaches. Given the nascence of the storage industry, the Commission should resist the utilities' rush to concentrate on a limited range of technologies, approaches, and applications. The AB 2514 plans are part of the early deployment of storage, for the state, nationally, and even globally. The Commission Staff Reference System Plan for the 2017–2018 Integrated Resource Planning cycle recommends an additional 2 GW of grid storage.[2] Implementing a range of storage technologies, configurations, and applications will provide information on the costs, benefits, advantages, problems and solutions for the tested options. That broader approach would enable emerging companies to develop new technologies and services and create jobs.

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[1] These comments were drafted by Paul Chernick, the president of Resource Insight, Inc., and the author of SBUA's comments on the AB 2868 issues (Aug. 9, 2018). Mr. Chernick's qualifications are submitted as an Exhibit to his AB 2868 direct testimony.

[2] http://cpuc.ca.gov/uploadedFiles/CPUCWebsite/Content/UtilitiesIndustries/Energy/EnergyPrograms/ElectPowerProcurementGeneration/irp/AttachmentA.CPUC_IRP_Proposed_Ref_System_Plan_2017_09_18.pdf

The benefits of diversification primarily accrue to future procurements that can be improved by the experience gained from the AB 2514 projects. Using the legislative mandate to spur diversification can benefit all ratepayers, including small businesses, by elucidating the least-cost, best-fit technologies for a wide range of applications. Identifying and confirming the comparative advantages of different technologies, and demonstrating the approaches, will reduce costs in each subsequent procurement.

As the storage industry matures, experience may demonstrate that lithium ion (Li-ion) should retain its dominance and that efforts to spur broader innovation do not yield cost-effective alternatives. If Li-ion is inherently dominant, the Commission will benefit from finding that out in the near future, allowing California planners to close the door on other options with confidence. But if cost-effective alternatives are developed for some applications, then all ratepayers will benefit in the long run with non-lithium ion storage options. The longer development of those alternatives is delayed, the greater the opportunity cost of ignorance.

Prioritizing technological diversity can help build an innovation ecosystem by enabling novel innovations to access capital, resources, and customers.[3] Diversification can also help buy down the cost of storage technologies that are in an earlier stage of commercialization, fostering start-ups, generating business opportunities, and creating new jobs to serve the California, national and global markets.

The increased knowledge base and capability would create additional options for the Commission, the utilities, and the state in general in coming years. These benefits better position the state for long-term optimal outcomes, including increased ratepayer benefits, reduced costs, and accelerated climate change mitigation.

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[3] https://www.energy.gov/sites/prod/files/2016/07/f33/AmpedUpvol2i3_WEB.pdf

II. Diversification efforts should encompass multiple dimensions

There are many dimensions to technological diversification. When developing its diversification goals, the Commission should consider the following aspects of diversity:

- A. Form of storage and energy return
    - 1. For electricity:
        - a. kinetic (e.g., flywheels)
        - b. compressed air
        - c. gravitational (e.g., pumped hydro, rail energy storage)
        - d. thermal (molten salt)
        - e. electrochemical
            - i) A variety of lithium-ion battery chemistries,
            - ii) sodium-sulfur,
            - iii) flow batteries (zinc bromide, vanadium),
            - iv) advanced lead-acid
        - f. For end-use energy:
            - i) hot water,
            - ii) ice for space cooling and other uses,
            - iii) compressed air
- B. Implementation and technology approaches, such as:[4]
    - 1. Location at substations, feeders, circuit branches, and behind-the-meter
    - 2. Isolating portions of the distribution system to serve microgrids
    - 3. Integration of storage with behind-the-meter solar
    - 4. Sharing batteries among customers in a building.

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[4] PG&E recognizes that technology diversity includes diversity in both use cases and technology. (Vol. 1, p. 5-17)

III. The Commission should be concerned that specific Li-ion chemistries dominate the current procurements, and should direct the utilities to fully examine and adopt alternative Li-ion systems to fulfill the goal of technological diversification

Lithium ion batteries are not so much a specific technology as a broad category. The feature common to all Li-ion batteries is that a lithium ion moves through electrolyte from the cell's anode to its cathode during discharge. There are many possible electrolytes, cathode and anode materials, and separators within the general Li-ion category. They have different chemical, structural, cost, performance, and safety attributes. Today, two lithium-ion cathodes dominate: nickel-manganese-cobalt layered oxides (NMC, $LiMnCoNiO_2$) and lithium manganese oxide (spinel, $LiMn_2O_4$). Even within the NMC category, batteries use varying ratios of those three metals, including the 25-year old $LiCoO_2$ design. These chemistries are used in a vast majority of the Li-ion cells today, whether for portable devices, transportation, or grid storage applications.

There are other Li-ion chemistries which are well studied, but less widely deployed, that might be of interest to the Commission, such as lithium iron phosphate (LFP, LiFePO4). For example, LFP batteries are safer and have longer cycle lifetimes than other chemistries, but have lower energy densities and slower discharge (as discussed in response to Question 2(d), below). There are dozens of other Li-ion systems that remain the subject of academic exploration, but currently lack sufficient commercialization to be relevant to the mandate.

IV. Responses to questions from the Commission requesting comments on issues pertaining to Energy Storage Technology Diversity

In accordance with the August 8, 2018 "Assigned Commissioner's and Assigned Administrative Law Judge's Ruling Requesting Comments on Issues Pertaining to Energy

Storage Technology Diversity," my testimony below responds to specific questions (noted in bold and italics) from the Commission:

1. ***To date, approximately 89% of the contracts executed pursuant to the Commission's Energy Storage Procurement targets established in D.13-10-040 have been lithium ion batteries. There has also been an observed trend that the diversity of technologies bidding into Investor-Owned Utilities' Requests for Offers has become more limited from the 2014 solicitation to the 2016 solicitation.***

    1.1 Can the Commission's stated goal in D.13-10-040 of transforming the energy storage market be considered achieved if a single energy storage technology comprises the majority of the owned and operated storage systems in PG&E, SCE and SDG&E's service territories? Why or why not?

Transformation of the energy storage market is not likely to result from deployment of a single technology. SBUA considers market transformation to include more than buying down the cost of future installations. Simply installing a certain quantity of storage in California or reducing the cost per kilowatt of storage by a target percentage is not market transformation, any more than installing a lot of T8 fluorescent tubes transformed the efficiency market. Transformation means changing the market to create long-term improvements (least cost and best fit) in a range of applications, by accelerating technology adoption and removing impediments.

Many of the market impediments identified in D.13-10-040 are not technology-specific, such as the lack of cohesive regulatory framework, the lack of cost-effectiveness evaluation methods, and the lack of cost transparency and price signals. These market impediments could theoretically be remedied without any storage installed at all. Other barriers such as the lack of commercial operating experience and lack of definitive operational needs require hands-on experience with various storage technologies.[5] The 1,325 MW storage mandate allows for accelerating technology adoption and learning

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[5] Order p 7, D.13-10-040, http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M078/K912/78912194.PDF

about the operational abilities and limitations of various products. Learning will probably not be maximized if 89% of storage contracts are for a single technology.

As discussed in response to the next question, the storage landscape is broad, with many possible technologies tailored to various operational requirements. General-purpose technologies, such as lithium-ion batteries, are least-cost and best-fit in some applications. In other cases, specialized products offer tailored features that allow for better performance and reduced costs.

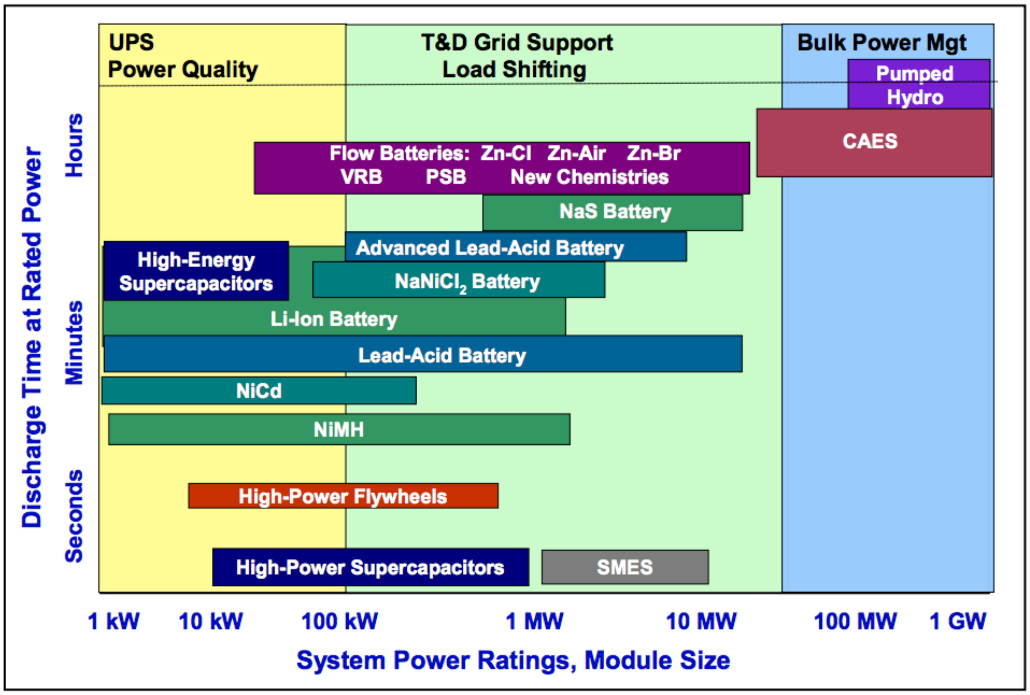
Lithium-ion batteries may be the Swiss army knife of the storage sector, but no one wants a kitchen stocked only with multi-function pocket knives. The historical diversity of conventional power plants highlights the benefits of a robust range of technologies, including baseload plants with higher capital costs but lower operating costs and peakers with the reverse. Together, these technologies complemented one another and allowed for lower cost electricity generation than either one individually. Similarly, a portfolio of complementary storage technologies will allow for a least-cost, best-fit build-out, where there are larger and smaller products, longer- and shorter-duration technologies, and so on.

2. Are there any grid or ratepayer-beneficial attributes of energy storage that storage technologies besides lithium ion batteries may adequately provide (i.e. long duration, safety)? If so, what are they? Are these attributes already captured in the utilities' cost-effectiveness valuation methodologies? If so, are they quantitative or qualitative values? Please list the relevant energy storage technology associated with each attribute.

Yes. Lithium-ion batteries are a middle-of-the-road technology, which simultaneously explains why they are so popular, but also why other technologies may offer greater grid or ratepayer benefits in specific applications. Sandia National Laboratory highlighted the range in possible storage technologies in 2013, reproduced as

Figure 1.[6] The figure positions fourteen technologies by their power and energy capabilities. It does not consider technologies that return end-use energy, such as thermal storage.

Figure 1: Positioning of Energy Storage Technologies



Lithium-ion chemistries cover only a portion of the possible storage landscape. Other systems may be preferable for bulk power management, or for applications where discharge time is very short or quite long. The Commission's energy storage mandate may be unable to materially foster storage technologies needed for bulk power management, given their large size, but the other domains and time frames are feasible.[7] Super-capacitors, flywheels, flow batteries and other electrochemical systems are

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[6] https://www.sandia.gov/ess-ssl/publications/SAND2013-5131.pdf figure 19. Reproduced from Sandia National Laboratory's "Energy Storage Handbook", Fig. 19. These comparisons are very general, intended for conceptual purposes only; many of the storage options have broader duration and power ranges than shown.

[7] See discussion in "Decision Adopting Energy Storage Procurement Framework and Design Program", Rulemaking 10-12-007, at 19, for the rationale for excluding most pumped hydro resources from the mandate. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M078/K912/78912194.PDF

permitted under the mandate but rarely implemented. These alternative technologies may offer superior performance for some storage applications such as long output duration, high output power, low losses while in standby mode, greater safety, and the like.

The following six sections each discuss one technology that may provide "grid- or ratepayer-beneficial attributes" as well or better than conventional lithium-ion battery configurations.

Long-Duration Storage

Conventional lithium-ion configurations do not generally provide storage for more than four hours output at rated capacity. One set of set of technologies for long-duration storage are the so-called flow batteries, which have flexible power/duration configurations that would be beneficial for some reliability and resiliency applications. Unlike lithium ion batteries, where power and duration generally scale proportionally for chemical or structural reasons, flow batteries can scale power and duration independently.[8] This allows for both (a) long-duration batteries; (b) batteries tailored to specific power and duration requirements.

Some benefits of storage duration are reflected in the quantitative cost-effectiveness evaluation methodology, but it is difficult to determine how well these benefits will be considered. Duration would affect Net Market Value (NMV), if the modeling includes the value of moving energy from weekends to weekdays, for example. The benefits of increased storage duration for reliability and resilience may be reflected in the Portfolio Adjusted Value (PAV), depending on how the utilities determine that value.

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[8] E.g., Li, L., Kim, S., Wang, W., Vijayakumar, M., Nie, Z., Chen, B., Zhang, J., Xia, G., Hu, J., Graff, G., Liu, J. and Yang, Z. (2011), A Stable Vanadium Redox-Flow Battery with High Energy Density for Large-Scale Energy Storage. Adv. Energy Mater., 1: 394-400. doi:10.1002/aenm.201100008. https://availabletechnologies.pnnl.gov/media/333_926201145351.pdf

Duration will not be fully considered if the utilities RFPs do not fully monetize increased duration. For example, if a utility only asks for shorter-duration storage proposals, then bidders are unlikely to offer a flow battery's longer duration.

High-Power, Short-Duration Storage

Super-capacitors and flywheels may be beneficial for exactly the opposite reason as flow batteries: they provide fast-response, high-power but short-duration storage. For example, super-capacitors may improve reliability by mitigating rapid voltage changes at solar facilities caused by intermittent cloud cover.[9]

These benefits are even less likely to be incorporated in the NMV and PAV than those of flow batteries. Unless the utility reflects these benefits in its RFPs, the fast-response benefits of super-capacitors and flywheels may go unmeasured. The specific benefit of assisting intermittent resource integration may be treated qualitatively.

Standby Capability

In the AB 2868 storage preceding, many of the utility proposals relate to providing reliability benefits to public-safety infrastructure. These batteries act as a replacement for diesel backup generators. In these applications, having a battery that can remain idle for long periods of time without meaningful losses in energy storage enhances reliability. Flow batteries can sit idle for very long periods of time without losses. They then can serve critical facilities for long periods, until the grid can be restored.

Standby capability does not appear to be included in the cost-effectiveness methodologies as either a quantitative or qualitative metric.

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[9] https://news.duke-energy.com/releases/duke-energy-to-put-new-battery-and-ultracapacitor-system-to-the-test-in-n-c

Safety

Storage systems can pose a variety of safety risks, which may be more important in some applications and locations than others. Safety varies with at least three factors: (1) underlying electrochemical reaction; (2) battery cell engineering; (3) balance-of-system engineering.

Some electrochemical systems are intrinsically safer than others for chemical or structural reasons.[10] For example, lithium-iron-phosphate batteries offer excellent safety due to good structural stability and good chemical stability.[11] NMC batteries, by contrast, have better operational characteristics but worse chemical and structural stability, increasing risk of failure.

Battery cells can be more or less safe, given the same underlying electrochemical reaction. For example, lithium-ion batteries sometimes catch fire when the porous separator that keeps the electrodes apart is punctured.[12] Careful engineering and manufacturing can minimize the risk of such failures. Measures of battery design safety should be reflected in the RFP process, with greater emphasis on testing and certification for batteries to be located in sensitive locations.

In addition to the battery cells, energy storage systems contain various other components, such as the inverter and the power plant controller, which monitors and executes storage operation. The entire system is an engineered product which may be of

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[10] "Structure" here refers to the underlying crystal structure of the battery cell, not the balance of system or engineering structure containing the cells.

[11] E.g., Chunli Gong, Zhigang Xue, Sheng Wen, Yunsheng Ye, Xiaolin Xie, "Advanced carbon materials/olivine LiFePO4 composites cathode for lithium ion batteries", *Journal of Power Sources*, Volume 318, 2016, Pages 93-112, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2016.04.008; and Wang, J., & Sun, X, "Olivine LiFePO4: the remaining challenges for future energy storage". *Energy & Environmental Science*, . 2015, *8*(4), 1110–1138. JOUR. http://doi.org/10.1039/C4EE04016C

[12] https://cen.acs.org/articles/94/i45/Periodic-graphics-Li-ion-batteries.html

varying quality and/or safety. The safety of a system can be assessed by various standards bodies such as Underwriters Laboratory.[13]

Safety is a qualitative metric in the utility cost/benefit analyses, but it is unclear whether the utilities consider cell safety, system safety, or both, and whether they reflect safety as a binary (safe/unsafe) or a continuous variable. For example, PG&E's description of its cost-benefit analysis methodology is just a few lines.[14]

Storage Medium and Form of Returned Energy

There may be benefits to energy storage technologies which return (or discharge) energy in a form other than electricity. For example, thermal storage (hot water, ice for space cooling) have higher efficiency than other storage technologies because the output does not need to be converted into a useful form – the stored product is the useful form.

Similarly, there may be benefits to other storage media. While outside the scope of the mandate, pumped hydro storage is able to cheaply and efficiency store vast quantities of energy in the form of potential energy (gravity) using water instead of electrochemical reactions. Compressed air energy storage (CAES) offers the same bulk power management opportunities as pumped hydro, but also suffers from geological constraints (certain geological features are required to store the air underground). PG&E's pilot CAES project identified several candidate locations at depleted natural gas fields, but the program appears moribund.[15] The Office of Scientific and Technical Information at the Department of Energy concluded that the PG&E CAES project had notable technical attributes but high costs compared other alternatives:

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[13] https://www.ul.com/newsroom/pressreleases/ul-issues-first-ul-9540-certified-home-energy-storage-system-to-enphase-energy/

[14] PG&E Pre-filed Testimony, Volume 1 of 3, page 5-17.

[15] The web page was last updated in 2014. https://www.pge.com/en_US/about-pge/environment/what-we-are-doing/compressed-air-energy-storage/compressed-air-energy-storage.page

> "The project demonstrated the technical feasibility of using an abandoned natural gas reservoir for storing high-pressure compressed air for a 300-MW-by-10-hour CAES facility. The reservoir at the King Island site was shown to be capable of accommodating the flow rates and pressures necessary for the operation of the facility. However, the estimated high cost of a CAES facility will have to be addressed in the context of the cost of alternative energy storage technologies."[16]

It does not appear that diversity in storage medium or returned-energy format are considered in the utility cost-benefit analyses.

Implementation Approach

Technological diversification can extend beyond the storage unit itself. Alternative connection technologies could increase the number of customers and quantity of load for which the procurement of storage is a cost effective. This sort of diversification is technology agnostic. For example, existing approaches to installing behind-the-meter storage work well for an office building occupied by a single customer or a single large store. But if the same office building or retail space is subdivided, with many small tenants (who will often be small businesses), a behind-the-meter storage system for each customer may be prohibitively expensive, even if the aggregate building load profile is identical to the single-tenant building. Developing a program that enables small tenants (and the building's common space) to share a single on-site storage facility would reduce unit costs (due to economies of scale in both equipment and overhead costs) and broaden the range of customers that could benefit from the resilience value of energy storage. This option would require that the utilities develop the ratemaking and contracting mechanisms to allocate costs and benefits of the storage system among the participants.

Benefits of expanding participation in the storage sector and increasing the equity of access to storage services do not appear to be included as either a qualitative or

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[16] https://www.osti.gov/servlets/purl/1434264

quantities metric in the utility cost-benefit analyses. SBUA recommends that the Commission require the utilities to explore and adopt additional connection technologies that will increase the benefits of storage, for small business and other ratepayers.

3. *Are there risks to ratepayers and the grid of utility energy storage portfolios comprised predominantly of a single energy storage technology?*

Yes. The storage market risks drifting towards a sub-optimal technical lock-in, where one dominant technology drives potentially preferable alternatives out of the market prematurely. A recent whitepaper from the MIT Energy Initiative argues storage faces excessive market concentration that may stall other storage technologies.

An even more worrisome risk is that innovations that could improve on the dominant design become "stranded" and never fully mature. Li-ion batteries are well-suited to transportation applications, but not necessarily ideal for the grid. Lock-in on Li-ion batteries is already making it difficult for producers of alternative storage technologies to survive, much less continue to innovate and scale up.

Public policy-makers should take action to build on the opportunities and mitigate the risks identified by these two interpretations of the near future of grid-scale energy storage. The objectives of such action should include growing the grid-scale energy storage market overall, creating niches within the market in which a range of technologies have opportunities to establish their cost and value characteristics, and ensuring that R&D continues in order to expand the portfolio of technology options.[17]

Promotion of lithium-ion battery storage systems has doubtlessly enabled and enhanced the storage market. System prices have declined, while storage installations have increased, both of which are favorable trends. While lithium-ion dominance has created short-run economic benefits, continued focus on that one technology may retard technologies (or configurations) that could eventually provide even better options for some applications. Failure to prioritize diversification today runs the risk of significant lost opportunities in the future.

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[17] https://energy.mit.edu/wp-content/uploads/2018/04/Energy-Storage-for-the-Grid.pdf

4. If the Commission were to direct the utilities to prioritize technology diversity in their 2018 solicitations, but there are not enough sufficiently cost-effective bids to allow them to meet their 2018 procurement targets, does the 2020 solicitation provide sufficient opportunity for the utilities to procure the remaining capacity to meet their targets in a cost-effective manner?

Yes. SBUA believes that technological diversity can be satisfied with a relatively modest amount of alternative storage capacity, and the utilities are unlikely to have difficulty meeting capacity targets, even if diversity were required. See also the response to Question 5 for possible modifications to the procurement process to help encourage diversity without burdensome cost increases for ratepayers.

5. If the Commission were to direct the utilities to procure a minimum amount of non-lithium ion technologies from their 2018 solicitation, what should that minimum threshold be based on, for example a minimum percentage of total capacity procured, a minimum number of energy storage technologies, or another metric/basis? If so, what would be an appropriate minimum threshold to ensure sufficient diversity in the procurement?

Given the threat of sub-optimal technological lock-in, and the reduced learning potential associated with a single dominant technology, the Commission should more strongly pursue non-lithium ion technologies.

It is not clear whether the lack of current technological diversification is the result of (1) bidders not offering these alternative technologies into AB 2514 procurements, (2) alternative technologies being screened out because they are more expensive than lithium-ion competitors, or (3) some combination of the two. Bidders may not be offering technologies due to their lack of imagination, inherent shortcomings of the technologies, market barriers, or the language of the RFPs and RFOs. The best approach to encouraging diversification depends on where the problem lies. The Commission might best have appropriate Staff or consultants review the unsuccessful bids and consult with actual and potential bidders to determine the root cause of low diversity.

One approach to encouraging diversity would be for the Commission to create an explicit carve-out, perhaps on the order of 10% to 20% of the 2018 and 2020 procurements (36.5 to 73 MW for 2018; 49 to 98 MW for 2020). This would be large enough to allow technologies that work best in larger formats (e.g. flow batteries for peaker replacement) an opportunity to participate more than once and make the procurement of alternative resources more than a box-checking exercise. Within this carve-out, technology diversification should be promoted. Mandating utilities procure 500kW to 2MW of a number of different technologies would provide real learning opportunities to the Commission, utilities, installers and operators. This range is arbitrary, but its upper bound is still lower than the size of the proposed AB 2868 behind-the-meter pilot programs.

Alternatively, if less encouragement is required, the Commission could direct the utilities to modify their cost-benefit assessment to incorporate a percentage adder bonus for alternative technologies. For smaller projects (under 20kW per installation, up to 5 MW overall) this adder should be substantial (50%): that is, an alternative technology costing 50% more than lithium ion should be treated as its equal from a cost perspective. For larger projects, the diversity adder should be more modest (10% to 20%). An overall limit on capacity subject to the adder could be incorporated to manage overall AB 2514 costs (the same 10% to 20% of the 2018 and 2020 procurements). The adder, paired with a cap, should encourage alternative storage technologies without unreasonably increasing costs.

All else equal, the diversity adder would be preferable to the rigid carve-out because it better allows for competition across technologies.